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A6_6 Venusian Vacation

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Abstract

In this paper, we investigate the conditions required to ensure human survival on Venus, along with the effects of the Venusian climate on the astronauts and the spacecraft. By considering thermal conductivity and Young's modulus, we find that 78 MW of power would be required to maintain a room temperature environment within the spacecraft and a human would last 47.5 s before succumbing to the high temperatures. It is also found that Tungsten is an ideal material to prevent damage from Thermal expansion due to its tensile strength.

Introduction

Venus is the hottest planet in the solar system, with average surface temperatures reaching 737 K [1]. In this paper, we will explore some of the conditions required to accommodate humans on the Venusian surface, along with the impact of the planet's climate on in-situ space missions. We will explore the power required to maintain room temperature within the spacecraft, the thermal expansion of the spacecraft, and the time taken for a human to succumb to the planet's temperature without a cooling system.

Theory and Results

First we must consider the dimensions of the hypothetical spacecraft. We will assume that the spacecraft is 48 m long, and that it consists of a room with a 5 m diameter. It will have a wall thickness of 2 m which gives a total diameter of 9 m, and therefore a radius of 4.5 m. The total surface area of the spacecraft is calculated by assuming it is a cylinder, which gives a value of 1484.4 m^2. To calculate the power required to keep the astronauts from the Venusian temperature, we will first need to calculate the rate of heat conduction using the following equation [2],:

$$I = dQ/dt = -kA(\Delta T/\Delta x) \tag{1}$$

,where I is the thermal current (measured in W), k is the thermal conductivity coefficient, A is the area of the spacecraft, and $\Delta T/\Delta x$ is the temperature gradient (for this case, ΔT_1 is the difference in temperature, and Δx is the wall thickness). Assuming that the spacecraft is made from Aluminium, this gives a thermal conductivity coefficient of 237 $\mathrm{W\,m^{-1}\,K^{-1}}$ [2]. The difference between the temperature of Venus (737 K) and room temperature (293 K) is 444 K. This would give a thermal current of 78 MW, which is approximately 850 times the net power produced by the Kashiwazaki-Kariwa Nuclear Power Plant in Japan: the most powerful nuclear power plant in the world [3]. It is not feasible to maintain this level of power for any planetary mission, and solar power would also be impossible to maintain due to Venus' thick atmosphere. To calculate the time taken for a human to succumb to Venus' temperature (assuming that the spacecraft is not being cooled and that the human is not wearing a spacesuit), we will first need to calculate the energy required to increase the human body temperature (310.15 K) to a fatal temperature. This is done using the following equation [2],:

$$Q = mc\Delta T_2 \tag{2}$$

,where Q is the thermal energy, m is the human mass (70 kg) and c is the specific heat capacity of humans (3500 kg^{-1}) [4]. As humans are believed to die from hyperthermia at temperatures of around 333.15 K [5], $\Delta T_2 = 23$ K. This gives us an energy value of 5.6 MJ. Eq. (1) is then used to calculate the thermal current of the human, where $k = 0.59\ \mathrm{W\,m^{-1}\,K^{-1}}$, $A = 2\ \mathrm{m}^2$ and $dx = 4$ mm (skin thickness) [6]. ΔT_3 in this case is 427 K (the difference between body temperature and Venus' temperature). This gives us a thermal conductivity value of 1.24×10^5 W. Dividing the thermal energy by the thermal current, this gives us a time of 45 s.

The surface temperature will also have significant effects on the structure of the spacecraft, as objects expand when heated (especially metals). To investigate whether the thermal expansion of the spacecraft would damage it, we have combined the thermal linear expansion formula with the Young's modulus equation to obtain the following equation [2],:

$$F/A = Y\alpha\Delta T_4 \tag{3}$$

,where the ratio between force F and area A represents the tensile strength, measured in $\mathrm{N\,m^{-2}}$, Y represents Young's modulus and α is the coefficient of thermal linear expansion. In Aluminium's case, $Y = 70\ \mathrm{GN\,m^{-2}}$, $\alpha = 24 \times 10^{-6}$ K^{-1} [2], and $\Delta T_4 = 734.3$ K if we assume that the spacecraft has just landed on the planet's surface from orbit (and the temperature of space is 2.7 K [7]). This gives a tensile strength of 1.2 $\mathrm{GN\,m^{-2}}$, which is greater than the tensile strength of Aluminium: 90 $\mathrm{MN\,m^{-2}}$ [2]. This would mean that the spacecraft would likely get damaged once it descends onto the Venusian surface, and would risk exposing the astronauts to the harsh conditions of the planet. A material which would be strong enough to withstand the thermal expansion would be Tungsten, with a tensile strength of 150 $\mathrm{GN\,m^{-2}}$ [2]. However, Tungsten is much denser than Aluminium, and would likely be too heavy to be practical for any space mission.

Conclusion

We therefore conclude that the power required to maintain a room temperature environment within the spacecraft is equivalent to 850 nuclear power stations, a human would likely last less than a minute on Venus' surface without a spacesuit, and the material required to keep the spacecraft from sustaining damage from thermal expansion is too heavy for a space mission.

References

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